PAYLOAD ENCLOSURE NOISE REDUCTION

By

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INTRODUCTION

During launch, aerospace structures are subjected to very high acoustic pressures on the exterior surface of the vehicle. These pressures cause the relatively thin skinned panels and shell components of the structure to vibrate. Vibration of the exterior skin generates internal noise fields that in turn act as fluctuating pressure sources for internal equipment. Internal systems such as payloads within the upper stages of the launch vehicle are extremely sensitive to these fluctuating pressures. These payloads are enclosed by cylindrical and conical shells, which are called payload enclosures. To minimize payload vibrations, it is necessary to maximize the noise reduction through the enclosure structure.

DEFINITION OF PROBLEM

Noise reduction became a severe problem during design of the payload enclosure for the Skylab. When the Skylab program originated, the honeycomb Spacecraft Lem Adapter (SLA) was selected as the enclosure structure since it was developed hardware being utilized on the Apollo vehicle configurations. However, there arose several structural problems associated with the SLA that involved payload interference, separation constraints, and a payload weight margin. To alleviate these problems, a skin-stringer enclosure was designed by MSFC. A sketch of these enclosures is shown in Figure 1. The SLA enclosure was 4.3-cm (1.7 in.) thick honeycomb, 11.89 m (39 ft) in height, and 6.61 m (21.7 ft) in diameter. The skin-stringer enclosure was 12.5 m (41 ft) in height and also 6.61 m in diameter. The skin thickness was 0.10 cm (0.04 in) and the stringer spacing was 17.8 cm (7 in.). A comparison of the noise reduction capabilities of these enclosures is presented in Figure 2.

The SLA provided 5 to 10 dB more noise reduction across the frequency spectrum. It should be pointed out that most of the payload components and subsystems had been bought and/or tested to vibroacoustic levels based on the SLA noise reduction. Therefore, if the skin-stringer enclosure was to be used, its noise reduction capability must be increased to yield approximately the same internal acoustic levels as the SLA.

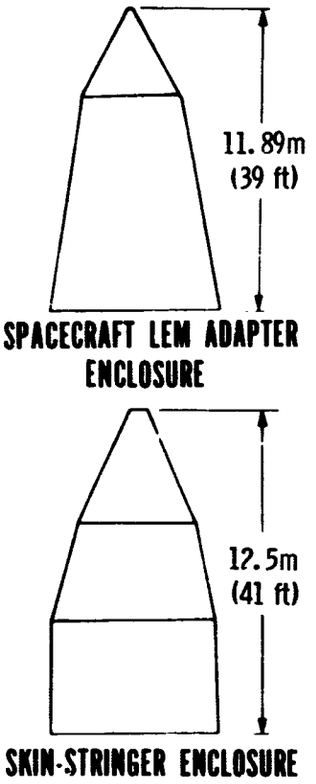

Figure 1. Skylab enclosure designs (Saturn IB wet workshop).

PROPOSED SOLUTION

Several techniques were considered for increasing the noise reduction of the skin-stringer enclosure. They are as follows:

1. Increase enclosure mass and stiffness to reduce enclosure vibration levels.

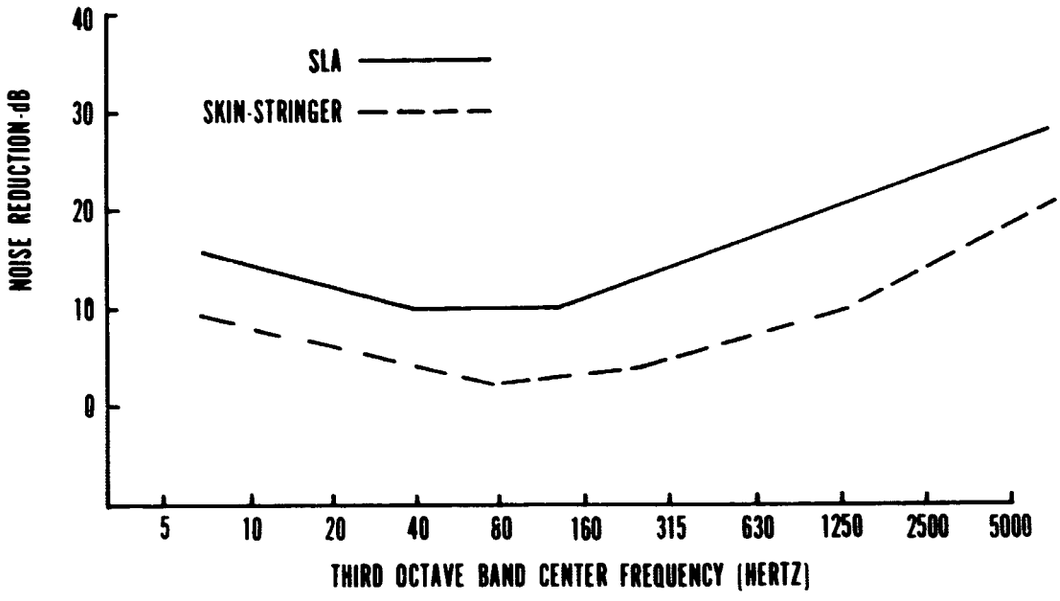

Figure 2. Comparison of noise reduction for SLA and skin-stringer enclosure.

2. Add absorption material to the internal surface of the enclosure to reduce the internal sound field.

3. Employ a light inert gaseous medium, such as helium, internal to the enclosure to provide an impedance mismatch between the air (external) and the helium (internal).

The first of these techniques was eliminated because of the payload weight restriction. The addition of an absorptive material and the utilization of the helium gas were selected for further investigation.

Helium was selected since it is the lightest, nonflammable gas available and therefore provides maximum noise reduction through a maximum impedance mismatch. The impedance of an unbounded acoustic medium is a function of ρC (the mass density times the speed of sound in the medium). The term ρC can be thought of in terms of momentum density. Since C is the speed of sound in the medium or the speed at which mechanical energy propagates in the medium, ρC may be regarded as the momentum per unit volume that may propagate through the medium. If a system is composed of two media having different values of ρC, an impedance mismatch occurs at the interface and the inefficiency of the system is increased. That is, the medium with the smaller value of ρC is capable of absorbing and transmitting a smaller amount of momentum than the medium with a greater value of ρC. The excess momentum remains in the medium of greater ρC in the form of a reflected wave [1]. The ratio of the impedance (ρC) of helium to air is approximately 0.407, and since the sound pressure level varies proportionally with the impedance, the expected noise reduction was predicted as follows:

$$\text{N.R.} = 20 \log \frac{\rho C \text{ He}}{\rho C \text{ Air}} = 8 \text{ dB}$$

A survey indicated that accomplishing noise reduction in this manner was without precedent and would require careful laboratory testing.

TEST PROCEDURE

An applied research test program was formulated to evaluate and verify the noise reduction capability of the helium and absorptive material. A series of acoustic tests was conducted in the MSFC acoustic research facility utilizing a monocoque stainless steel

cylinder 91.44 cm (36 in.) in diameter, 91.44 cm (36 in.) long, and 0.046 cm (0.018 in.) thick and capped at both ends. A typical test setup is presented in Figure 3. The test specimen was suspended from the ceiling of the reverberation room by bungee cords and was subjected to broadband random acoustic excitation [2].

Five microphones were distributed external to the cylinder, and five microphones were distributed internal to the cylinder. The helium purge inlet and outlet flow attachments were installed in the bottom cap. Samples taken from the bottom of the cylinder indicated a helium purity of at least 93 percent for each test run. The tests were conducted for the following configurations:

1. Unmodified cylinder with ambient air inside the cylinder.

2. Unmodified cylinder with the internal volume purged with helium.

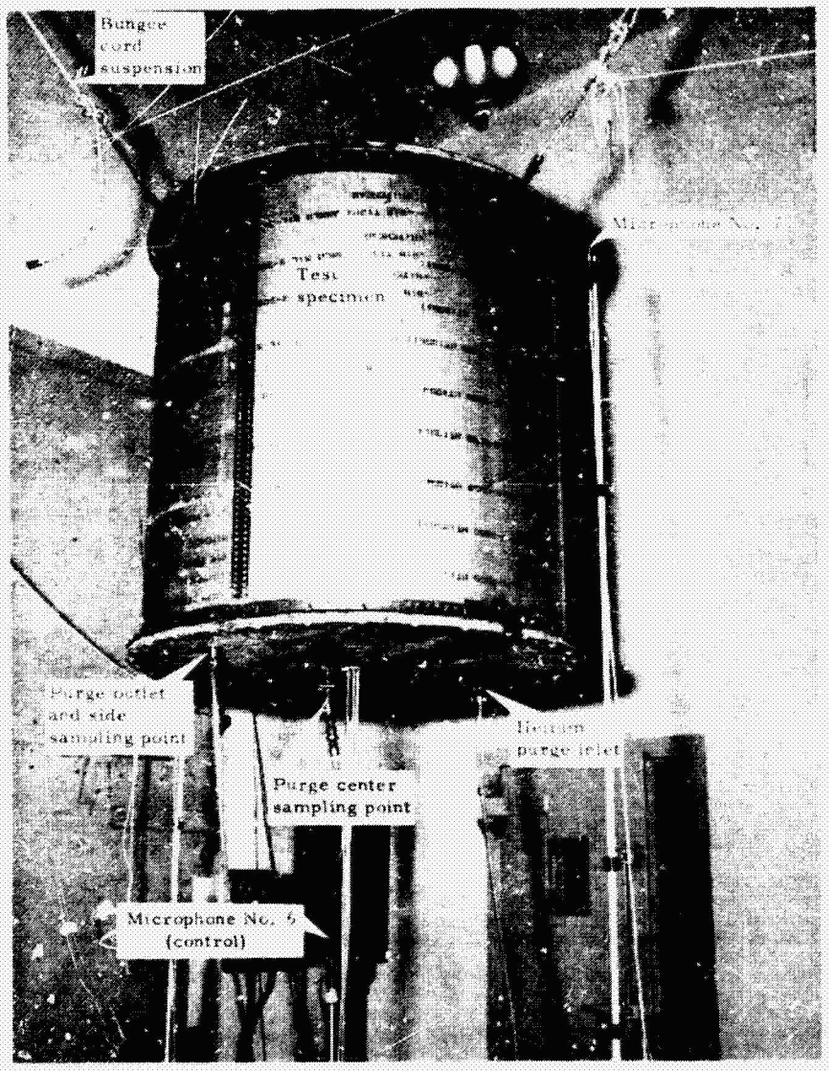

Figure 3. Typical test setup.

3. Cylinder modified with 2.54-cm (1-in.) thick polyurethane foam applied to all interior surfaces and ambient air inside the cylinder.

4. Cylinder modified with 2.54-cm (1-in.) thick polyurethane foam applied to all interior surfaces and the internal volume purged with helium.

DATA REDUCTION

Data from the microphones were recorded on magnetic tape. One-third octave band analyses were subsequently performed on the recorded data. The data were plotted in decibels at one-third octave band center frequencies. To obtain an estimate of noise reduction for the cylinder, the average internal microphone levels were subtracted from the average external levels, and the resulting noise reduction curves were plotted. This is the form in which the results are presented in this paper.

TEST RESULTS

The results from these tests show that the use of helium was quite effective in providing additional noise reduction. These effects are shown in Figure 4 by comparing the noise reduction measured when the cylinder was filled with helium and when filled with air. The air volume critical frequency at 182 Hz and the helium volume critical frequency at 530 Hz are volume resonance phenomena that are a function of the media. These resonances, as expected, are indicated by a decrease in the measured noise reduction. A significant decrease in noise reduction also occurred near the ring frequency, which was calculated to be approximately 1800 Hz. It is a

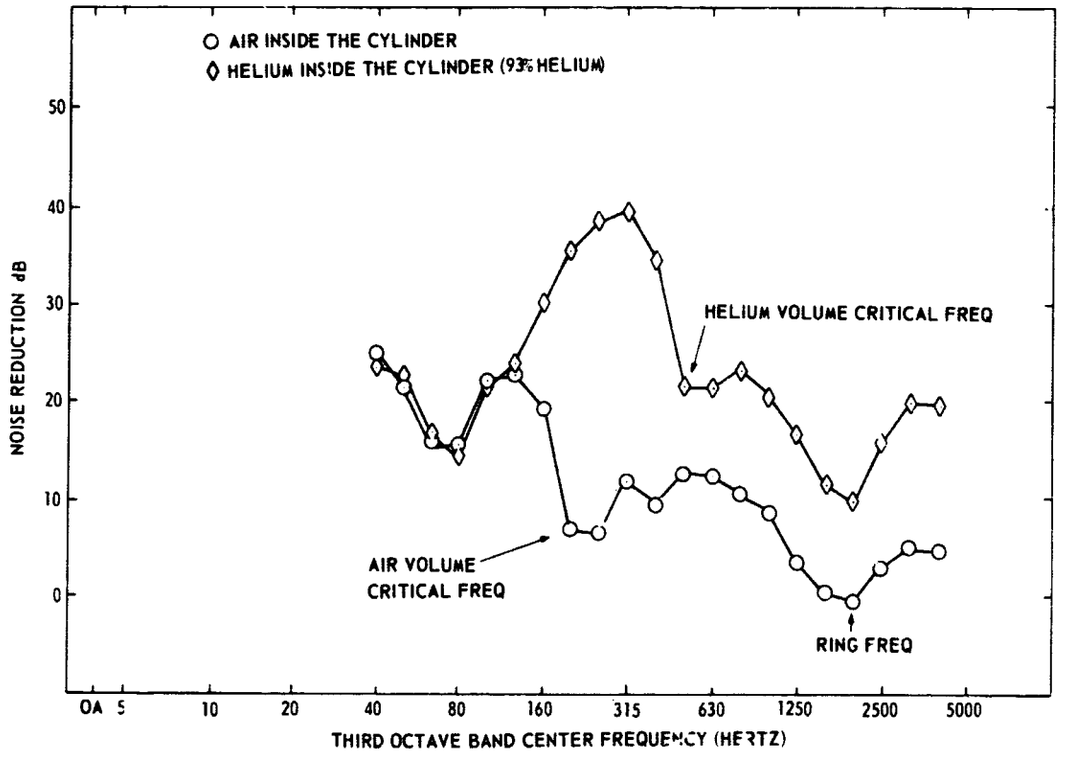

Figure 4. Noise reduction of a monocoque cylinder in a reverberant acoustic field.

well-known property of cylindrical structures that response is highest at the ring frequency, thus causing another decrease in noise reduction for both media. A large noise reduction was obtained in the frequency range between the air and helium volume critical frequencies. Above the helium volume critical frequency, approximately 8 to 10 dB additional noise reduction was obtained. In scaling from the test cylinder to the 6.61-m (21.7-ft) diameter payload enclosure, the air and helium volume critical frequencies would shift down in frequency to 25 Hz and 70 Hz, respectively. Thus, it can be assumed that the helium will provide 8 to 10 dB added noise reduction for the payload enclosure in the frequency spectrum above 25 Hz.

The noise reduction furnished by the absorptive material was frequency-dependent as shown in Figure 5. In the frequency band from 40 to 100 Hz, the absorptive material provided practically no noise reduction above that afforded by the cylinder. However, from 600 to 3000 Hz, reductions of 2 to 6 dB in sound pressure levels were obtained. An unexpected result was the magnitude of added noise reduction indicated from 100 to 600 Hz. This effect was attributed to the added mass and stiffness caused by the presence of the foam since the cylinder was monocoque and only 0.046 cm (0.018 in.) thick.

Another series of tests was run with the cylinder modified with the 2.54-cm (1-in.) layer of foam and purged with helium. These results, presented in Figure 6, show that the foam and helium furnished approximately 25 dB in the frequency range above the helium volume critical frequency. These results indicate a greater noise reduction than the added results of the helium and absorptive test taken separately. This observation implies that the absorption material was more efficient in the helium environment. However, no theoretical basis was found to support this observation.

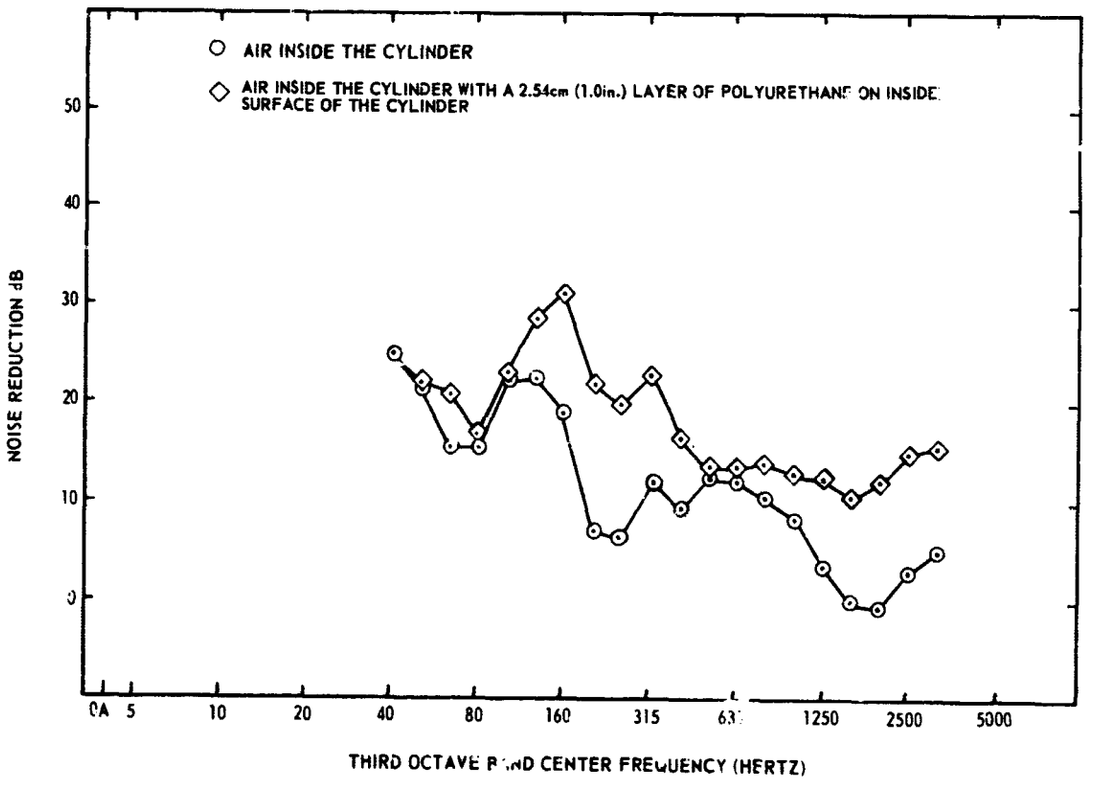

Figure 5. Noise reduction of a monocoque cylinder in a reverberant acoustic field.

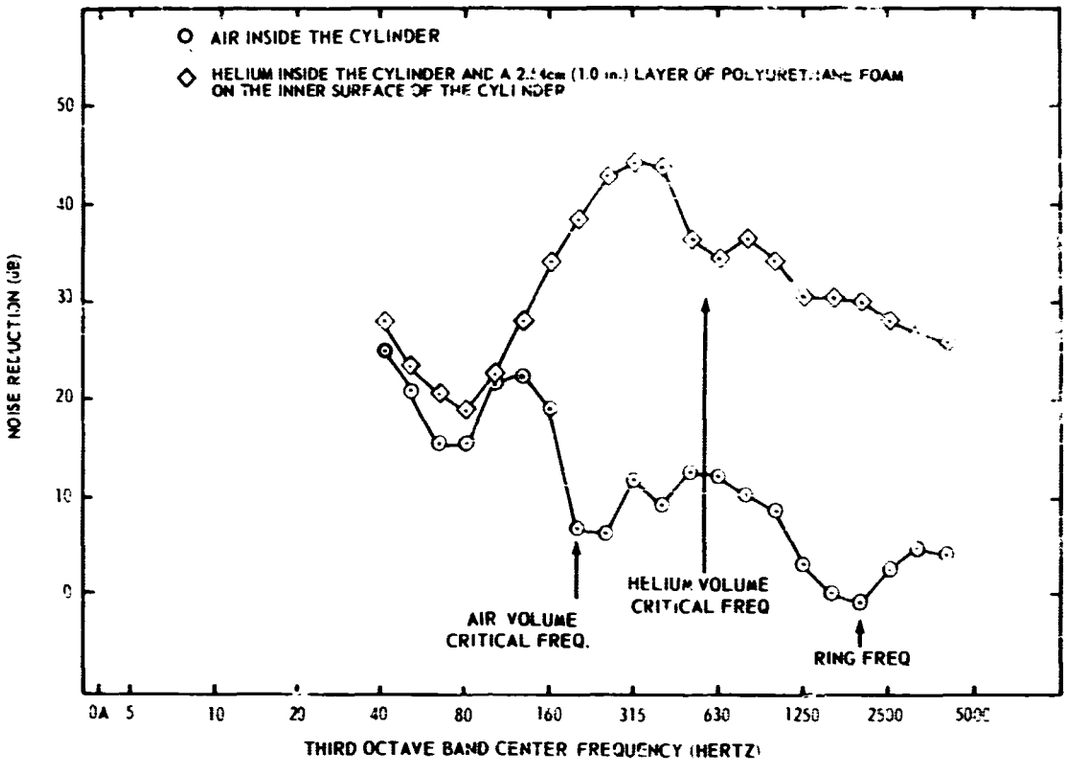

Figure 6. Noise reduction of a monocoque cylinder in a reverberant acoustic field.

CONCLUSIONS

An added noise reduction of 8 to 10 dB can be obtained for a cylindrical structure with an internal helium environment. The noise reduction provided by polyurethane foam absorptive material is frequency-dependent. Reductions of 2 to 5 dB were obtained in the frequency region of 600 to 3000 Hz. The conclusions from the helium test were the basis for an operational requirement to purge the payload enclosure with helium prior to launch. This requirement specified that a 93-percent helium environment be maintained up to 15 sec after launch.

Since the research effort reported in this paper, several additional acoustic tests have been performed to investigate the effect of a helium purge on component vibration response. A portion of these tests were sponsored under research contract NAS8-20260 with Wyle Laboratories. Another series of tests involved a large 6.71 m (22-ft) diameter cylinder mounted on the Mobile Acoustic Research Lab (MARL) test fixture located at the Mississippi Test Facility. The MARL was located near the test stands and exposed to four, stage-static-test exposures. During these exposures, the large cylinder was purged with helium. The results from these tests will be reported in the near future.

REFERENCES

1. Holmes, J. R.: Air-Helium Noise Reduction Studies. Wyle Laboratory, Research Staff Report WR70-3, January 1970.

2. Saunders, J. M.; and Cahill, J. B.: Acoustic Evaluation of Polyurethane Foam Lining and Helium Purging of AAP Payload Shroud. Summary Test Report, ASD-ASTN-1093, February 1970.